

**LOWCAL Ground Receiver: PMT  
Dark Current Measurement**

**by**

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# LOWCAL Ground Receiver: PMT Dark Current Measurement

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## Contents

<b>Contents .....</b>	<b>iii</b>
<b>List of Figures .....</b>	<b>iv</b>
<b>List of Tables.....</b>	<b>iv</b>
<b>1. Introduction.....</b>	<b>1</b>
1.1. Overview.....	1
1.2. PMT Operation.....	2
<b>2. Dark Current Measurement Process.....</b>	<b>3</b>
<b>3. Data Analysis.....</b>	<b>5</b>
3.1. Data Collection and Results.....	5
3.2. Error sources and analysis .....	6
<b>4. Conclusions.....</b>	<b>7</b>
<b>Appendix A PMT Dark Current Testing Procedure.....</b>	<b>9</b>
<b>Appendix B PMT Power Up and Power Down Sequences.....</b>	<b>13</b>
<b>References .....</b>	<b>14</b>

## **List of Figures**

Figure 1.1 PMT Block Diagram .....	2
Figure 2.1 PC104TSCE PMT Housing.....	3
Figure 2.2 Front Plate and Faceplate .....	3

## **List of Tables**

Table 3.1 PMT Dark current (nA) Results with Supply Voltage 1 kV .....	5
Table 3.2 Corrected Mean Anode Dark Current (nA) .....	6

## **1. Introduction**

This paper is part of a series of papers for a research project at New Mexico State University. The project is referred to as LOWCAL or Lightweight Optical Wavelength Communications without A Laser in space. While some of the material presented is specific to the LOWCAL project, the general procedure for measuring the dark current of a photomultiplier tube is presented.

### **1.1. Overview**

In optical communications, there are many devices that covert optical power into an electric current. The photomultiplier tube (PMT) is one of these devices. A PMT is used for two situations. First, low optical power is being received. Second, an extreme low noise device is needed. In the LOWCAL system both conditions are met making the use of a PMT optimal. The PMT has several factors that need to be characterized before it can be used. These are:

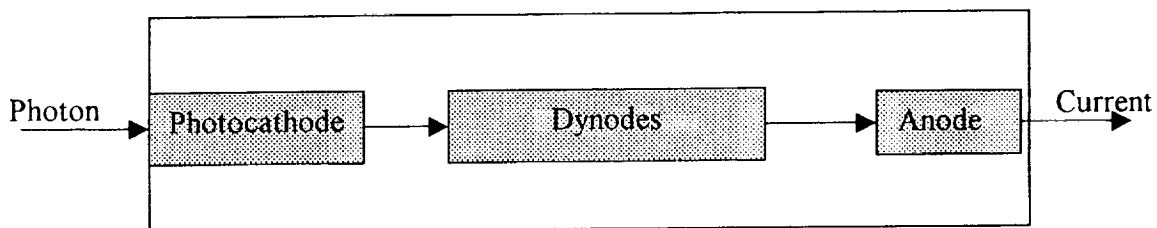
- Responsivity
- Gain
- Dark Current
- Quantum Efficiency
- Sensitivity
- Rise Time
- Transit Time

The manufacturer may give some or all of these, while all are needed to provide a complete system analysis. In the LOWCAL experiment the manufacturer of the PMTs used provided

values for all but quantum efficiency and responsivity. However, the dark current is of important interest because it plays a key role in the calculation of the signal-to-noise ratio (SNR). Even though the manufacturer provides a figure for the dark current the dark current of a PMT can change over time depending on use, supply voltage to the PMT and exposure of the photocathode to light. Therefore, an experimental method needed to be developed to quickly check the dark current each time a PMT was turned on.

## 1.2. PMT Operation

A PMT is a vacuum electron tube device that is divided into three parts: the photocathode, one or more dynodes, and the anode. By the photoelectric effect when a photon strikes the photocathode, a number of photoelectrons are ejected from its surface. Each

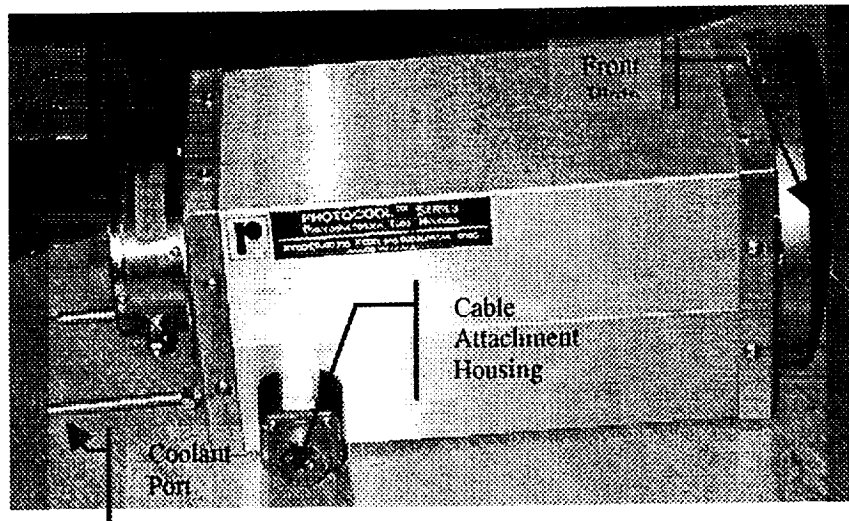


**Figure 1.1 PMT Block Diagram**

photoelectron is then accelerated by an electric field and hits the first dynode. This impact releases several more electrons that are further accelerated into the second dynode and so fourth. The overall effect is a gain in the number of electrons that eventually strike the anode. This produces a current. Figure 1.1 shows a block diagram of the PMT. There are two currents that leave the anode. One is the photocurrent produced by the photons and one is the dark current that is always present due to random emission of electrons due to other processes.

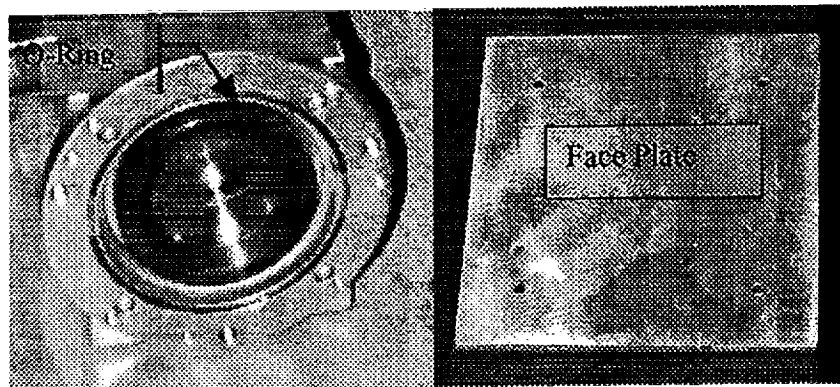
## 2. Dark Current Measurement Process

The dark current of the PMT can be calculated by measuring the current out of the PMT if there is no light on it. In order to do this a light tight housing is needed for the PMT. The LOWCAL experiment uses a PC104TSCE PMT housing (figure 2.1). This housing has a front



**Figure 2.1 PC104TSCE PMT Housing**

plate that allows for the mounting of equipment. This plate contains a 2" diameter window for the transmission of light. The housing also has an O-ring on it forming a light tight seal. Once



**Figure 2.2 Front Plate and Faceplate**

the PMT is in a light tight enclosure the anode current may be measured. Mounting a solid faceplate (figure 2.2) against the front plate of the PC104TSCE PMT housing formed the light tight enclosure.

Next step is to mount the PMT in the housing and test for light leaks. Appendix A gives the procedure for doing this. It is important to test for these leaks because they can give erroneous measurements. In doing the light leak test the voltage is slowly incremented. This is because at operation voltage a leak of unknown optical power can damage the PMT. Therefore, if the PMT shows a signal at a low voltage less damage will occur if any.

The data was taken using a Tektronix TDS 520 oscilloscope. This oscilloscope is a digital sampling scope and can sample up to 500 mega-samples per second. The voltage scale was set to 1 mV per division and the time scale was set to 1  $\mu$ s per division. The TDS 520 has the capability of calculating certain values and displaying them. Two of these values are the mean voltage and the RMS voltage. The mean voltage is the average DC voltage over one sample set, which is ten divisions (10  $\mu$ s for these settings). This value corresponds to the dark current of the tube. The RMS voltage is the average fluctuation of the signal. This is related to error in the signal. Once these values were found equation (2.1) was used to calculate the dark current.

$$I_{Dark} = \frac{V_{mean} \pm \frac{V_{rms}}{2}}{R_{trans}} \quad (2.1)$$

Now it is important to note that the voltage value from the PMT will always be negative. If a positive voltage is read there is an error with the measuring equipment or PMT.



### 3. Data Analysis

The results of the test gave rise to some interesting results. These pertained to the equipment used and the specifications given by the manufacturer. Therefore, a review of the problem and a plan to correct it will be set forth here.

#### 3.1. Data Collection and Results

The data collected consisted of 6 runs of 30 points each taken over a period of 1 week. The results were very interesting in that they showed a definite trend in the equipment used. Table 3.1 shows the results of these runs. The results show a trend indicating the PMTs used have a higher dark current than specified. There are two possible reasons for this: light leakage or a large D.C. offset in the system. Despite these factors it is evident that the dark current stays within a factor of 2.5 for each of the tubes. If the third run is removed this factor is reduced to a maximum of 2.25. Even though the experimental value differs from the specified value the test is still valid. The reason this is true is the offset errors were not taken into account when calculating the values for the currents. Once the error is taken into account the values are more in line with the manufacturer.

**Table 3.1 PMT Dark current (nA) Results with Supply Voltage 1 kV**

Hamamatsu R2228 PMT Dark Current (nA)				
Specified	TA4749	TA4735	TA4749	TA4735
	1.10	1.60	NA	NA
	Average Mean		Average RMS	
Run 1	2.22	2.73	.18	.2
Run 2	2.37	2.42	.11	.34
Run 3	2.65	3.21	.38	.52
Run 4	2.24	2.96	.12	.27
Run 5	2.45	2.33	.24	.41
Run 6	2.23	2.86	.31	.16

### 3.2. Error sources and analysis

One of the major sources of error was in the oscilloscope itself. The device has a D.C. offset that is approximately  $-120 \mu\text{V}$  (this value changes since a new offset is calculated every screen update) for the scale used. The scope provides no reasonably apparent way of adjusting this offset. Therefore, the offset was taken into account by manually subtracting the value from each data point giving the results shown in table 3.2.

**Table 3.2 Corrected Mean Anode Dark Current (nA)**

Hamamatsu R2228 PMT Dark Current (nA)		
Specified	TA4749	TA4735
	1.10	1.60
Average Mean		
Run 1	1.02	1.53
Run 2	1.17	1.22
Run 3	1.45	2.01
Run 4	1.04	1.76
Run 5	1.25	1.13
Run 6	1.03	1.66

These corrected values for the dark current are within 1.3 times the specified value. These values for the most part fall within the error bounds set by the rms voltage. Other sources of error that can occur in the dark current measurement are supply voltage ripple, load resistance, photocathode exposure, and digitizing noise. The most prominent of these sources is photocathode exposure. The more the photocathode is exposed to a light source of any kind over a period of time the more noisy the tube will be. Thermal stress and age will have the same effect on the tube. Load resistance causes an error in the measurement due simply to the fact that different loads on a PMT (or any current source) will draw a different amount of current. The next noise source in the experiment is digitizing noise. The TDS 520 is a digital sampling scope and inherently has quantization noise. The last noise source is the high voltage power supply

may have had either ripple or an error between what is displayed voltage value and what its output voltage. Either condition would cause error in the measured dark current.

Even though there is error in the dark current measurement, the results still indicate that the specified values of the dark current by the manufacturer are correct. The method used to obtain the data is valid. The analysis of the data evaluates all known error sources either qualitatively or quantitatively. This gives a good indication of the dark current of the PMT and a baseline noise of the tube.

#### **4. Conclusions**

The process outlined in this paper gives a good method of ascertaining the dark current of a PMT tube. While the manufacturer of the PMT should supply this value it is always a good check to see if the PMT is operating correctly. Any large variation from the supplied value indicates that the tube has been damaged. The two R2228 PMTs used for LOWCAL have a specified dark current of 1.6 and 1.1 nA, testing the dark current indicated that these values are what the tubes nominally produce.

The dark current test also provided the production of a procedure to safely power up and power down a PMT (see Appendix B). This is important since the PMTs are extremely fragile. A PMT is most vulnerable to power surges and optical intensity fluctuations. The procedure developed is designed to help prevent damage from these.

Since the LOWCAL experiment uses a housing that can easily be made light tight, the dark current test may be performed at any time by simply capping the input to the optical filter system. Sealing the PMT input from any light and measuring the voltage of the transimpedance

filter accomplishes this. The voltage than can be converted to a current and compared to the specified values. This gives a quick way of checking if the PMTs are performing correctly.

## **Appendix A PMT Dark Current Testing Procedure**

### **Equipment:**

- BNC Cable
- Faceplate
- Tektronix TDS 520 Oscilloscope or other comparable voltage measuring device
- PC104TSCE PMT Housing
- R2228 PMT Tube
- Lowpass transimpedance filter ( $R \approx 100 \text{ k}\Omega$ )
- High Voltage Power Supply
- High Voltage BNC Cable
- Desk Lamp
- Flashlight
- Black electrical tape

### **Procedure:**

#### **Part A: PC104TSCE PMT Housing Setup**

1. Mount faceplate to front plate

**NOTE: Do not use screws longer than ¼ inch.**

2. Unscrew rear plate from PC104TSCE housing (3 Philips pan head screws)
3. Remove rear plate from PC104TSCE Housing
4. Turn on desk lamp
5. Tilt desk lamp so that major portion of light is away from work area
6. Turn **OFF** overhead and/or all other room lights.

**NOTE: PMT is sensitive to light even when no power is applied**

7. Remove PMT from box (both PMT tubes and boxes have serial number)
8. Record serial number from tube
9. Insert PMT into rear plate (PMT pins and plate are keyed)
10. Remove PMT photocathode cover and set aside for later **DO NOT LOOSE**
11. Insert PMT-Rear Plate assembly into housing
12. Attach rear plate with screws

**NOTE: At this point the room lights may be turned on**

13. Attach photocathode connector to high voltage power supply using the high voltage BMC cable
14. Attach lowpass transimpedance filter to anode connector
15. Attach transimpedance filter to oscilloscope using BNC cable

#### **Part B: Data Collection Procedure**

1. Disconnect high voltage power supply from PMT Cathode connection
2. Turn on high voltage power supply
3. Make sure high voltage power supply is set to 0V
4. Turn off high voltage power supply
5. Connect high voltage power supply to PMT Cathode connection
6. If capable, set the output polarity of the high voltage power supply to negative
7. Connect the low pass transimpedance filter to oscilloscope
8. Make sure room lights are off

9. Turn on oscilloscope
10. Set oscilloscope to trigger off line
11. Set oscilloscope to 10  $\mu$ s per division time scale and 5 mV per division voltage scale
12. Turn on high voltage power supply
13. Slowly turn voltage to  $\sim 100$  V
14. Shine light source (flashlight) around seal noting any voltage jumps
15. If no voltage jumps turn voltage up to  $\sim 200$  V and repeat previous step
16. If the voltage jumps use black electrical tape to seal leak
17. Repeat steps 11 through 13 until voltage is 1 kV
18. After ensuring there are no light leaks set oscilloscope to 1  $\mu$ s time scale and 1 mV voltage scale
19. Set the oscilloscope to display mean value and rms value
20. Record 20 data points
21. Divide mean values by the resistance of the transimpedance filter to get the dark current.
22. Divide rms value by the resistance of the transimpedance filter to get an error estimate in current.

### **Part C PMT Removal Procedure**

1. Turn high voltage power supply to 0 V
2. Turn off high voltage power supply
3. Turn on desk lamp
4. Tilt desk lamp so that major portion of light is away from work area

5. Turn **OFF** overhead and/or all other room lights.

**NOTE: PMT is sensitive to light even when no power is applied**

6. Remove high voltage BNC cable from photocathode connector
7. Remove transimpedance filter from anode connector
8. Unscrew rear plate from PC104TSCE housing (3 Philips pan head screws)
9. Remove rear plate from PC104TSCE Housing
10. Place PMT photocathode cover on PMT
11. Remove PMT from rear plate
12. Place PMT in box making sure that serial numbers match

**NOTE: At this point the room lights may be turned on**

13. Attach rear plate to housing with screws



## **Appendix B PMT Power Up and Power Down Sequences**

1. Disconnect high voltage power supply from PMT Cathode connection on PC104TSE PMT Housing
2. Turn on high voltage power supply
3. Make sure high voltage power supply is set to 0 V
4. Turn off high voltage power supply
5. Connect high voltage power supply to PMT Cathode connection on PC104TSE PMT Housing
6. If capable, set the output polarity of the high voltage power supply to negative
7. Connect PMT Anode connection on PC104TSE PMT Housing to low pass transimpedance filter
8. Connect the low pass transimpedance filter to equipment to be used
9. Make sure room lights are off or light shroud is on PMT housing
10. Turn on high voltage power supply
11. Slowly turn voltage to -1 kV

### **Power Down**

1. Slowly turn voltage to 0 V
2. Make sure voltage reads 0 V
3. Turn off high voltage power supply

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